NORTH CAROLINA

DEPARTMENT OF WATER RESOURCES

DIVISION OF GROUND WATER

REPORT OF INVESTIGATIONS NO. 1

GROUND-WATER SUPPLY OF CAPE HATTERAS NATIONAL SEASHORE RECREATIONAL AREA

By

PHILIP M. BROWN

RALEIGH

1960

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Harry E. Brown, *Director*

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Harry M. Peek, *Chief*

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Geologist, U. S. Geological Survey

Prepared by the

UNITED STATES GEOLOGICAL SURVEY

in cooperation with the

NATIONAL PARK SERVICE

RALEIGH

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The Honorable Luther H. Hodges
Governor of North Carolina
Raleigh, North Carolina

Dear Governor Hodges:

I am pleased to submit Report of Investigations No. 1, "Ground-water Supply of Cape Hatteras National Seashore Recreational Area", prepared by Philip M. Brown, District Geologist, United States Geological Survey, in cooperation with the National Park Service.

This report gives the results of the first phase of intensive studies by the Geological Survey to evaluate and aid in the development of ground-water supplies in the Seashore Recreational area. It presents the data collected on Bodie Island and the procedures that should be followed in developing and protecting a permanent ground-water supply for existing and future facilities on the island.

Respectfully submitted,

Harry E. Brown

Harry E. Brown

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GROUND-WATER SUPPLY OF CAPE HATTERAS NATIONAL SEASHORE RECREATIONAL AREA, NORTH CAROLINA

By Philip M. Brown

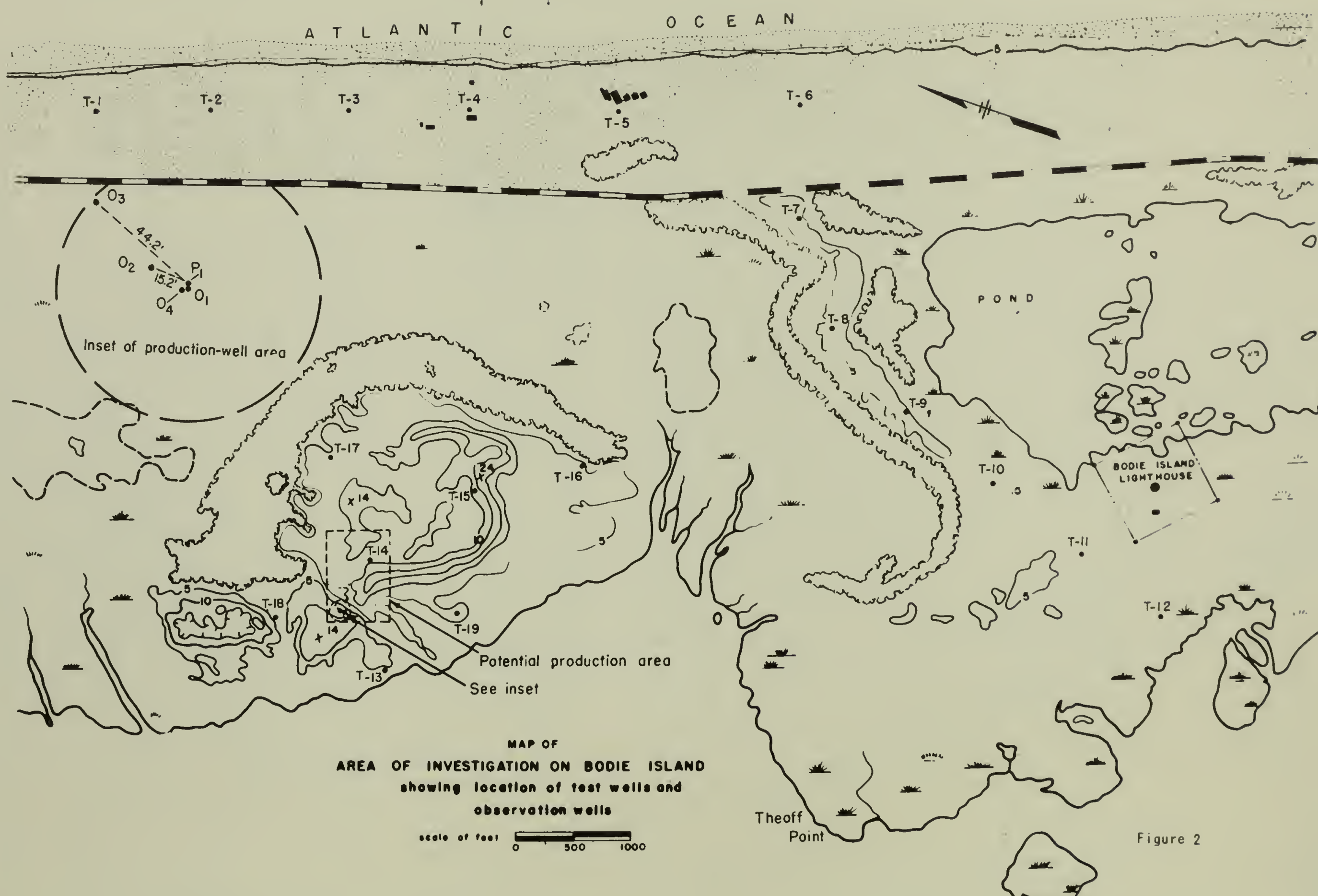
INTRODUCTION

In 1954 the National Park Service requested the U. S. Geological Survey to make a preliminary ground-water study of the Cape Hatteras area and to prepare a report which was to be included in an overall study of the geology, ecology, and oceanography of the Cape Hatteras area (fig. 1). In response to this request, a report entitled "Preliminary Report on the Ground-Water Resources of the Cape Hatteras National Seashore Recreational Area" was prepared in 1955 by H. E. LeGrand, Ground Water Branch, U. S. Geological Survey, in cooperation with the North Carolina Department of Conservation and Development. In 1957 the National Park Service requested additional help from the Geological Survey to aid in determining if an adequate ground-water supply could be obtained at certain places in the Cape Hatteras area. The Geological Survey's assistance has included establishing procedures and supervising collection by Park Service personnel of hydrologic data necessary for estimating ground-water supplies, analyzing the resultant data, and preparing this report.

This report, prepared under the general supervision of A. N. Sayre, Chief, Ground Water Branch, presents an evaluation of the available data and suggestions for a permanent ground-water supply on Bodie Island (fig. 2). The report covers the first phase of a continuing ground-water investigation by the National Park Service in the Cape Hatteras area.

The Park facilities extend along some 77 miles of barrier beach, termed the "outer banks," that forms the easternmost edge of North Carolina adjacent to the Atlantic Ocean. The narrow strip of beach is composed of three islands - Bodie, Hatteras, and Ocracoke - and the park facilities occupy a part of each island. Average precipitation ranges from 45 inches at Manteo to 55.47 inches at Hatteras (fig. 3), being greatest between July and October. In the area of investigation constantly shifting sand dunes as much as 30 feet high border the ocean side of the area, whereas low, swampy marshes generally border Pamlico Sound. Between the dunes and the marshes are low, relatively smooth sand flats.

Permeable sand lies at the surface of the area and quickly ad-



MAP OF
AREA OF INVESTIGATION ON BODIE ISLAND
showing location of test wells and observation wells

Figure 2

sorbs the rainfall, which moves downward to the water table and then laterally to discharge into the ocean and Pamlico Sound. Surface runoff, if there is any, is confined to the low marshes bordering Pamlico Sound.

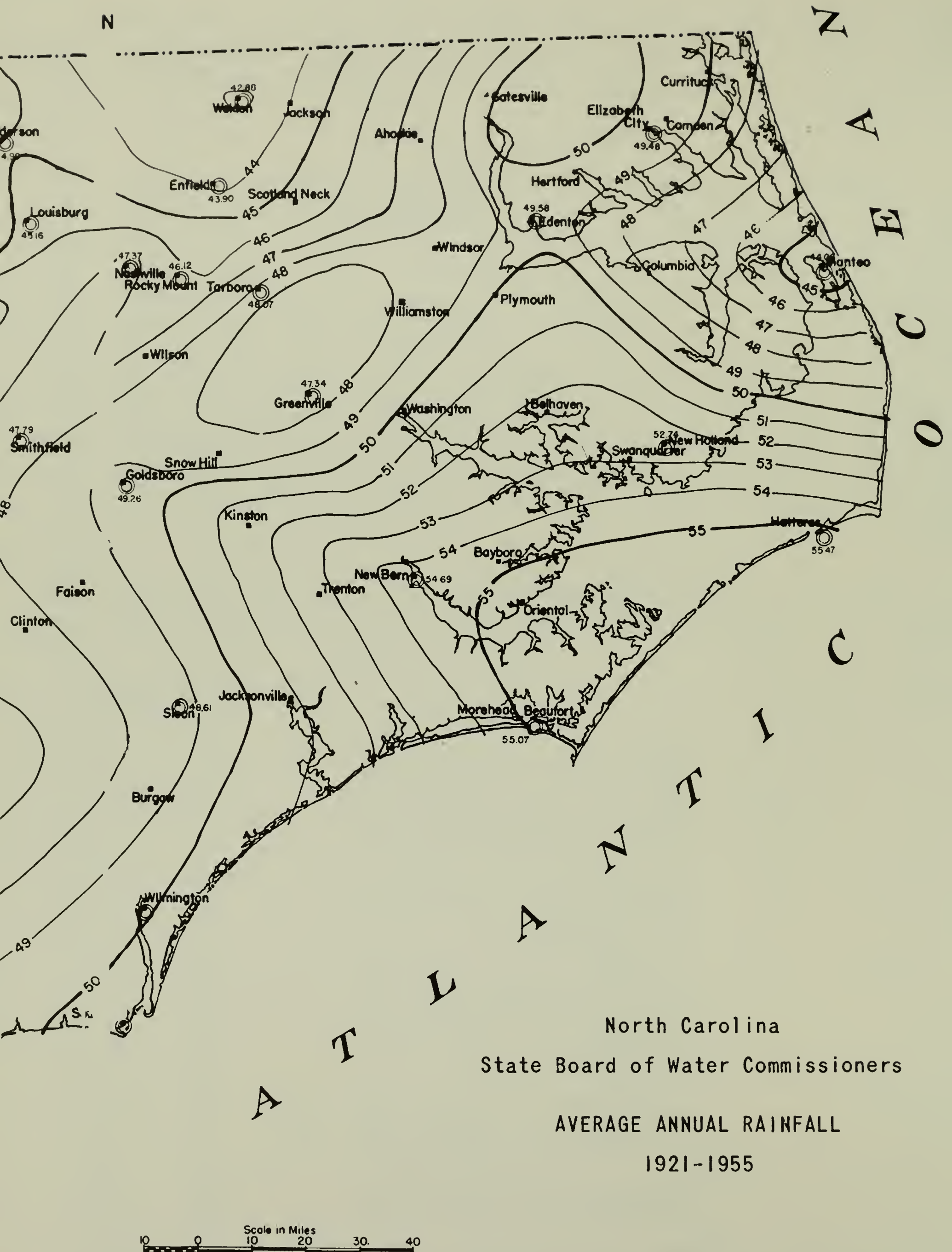
GEOLOGY

Nineteen test wells were drilled on Bodie Island to determine the nature and continuity of the sediments and the chloride content of their contained water. The test wells were located in three general areas (fig. 2) - parallel to the ocean front, normal to the ocean front and to Pamlico Sound, and adjacent to Pamlico Sound in an area of high dunes northeast of Theoff Point. The character of the material penetrated by the wells is shown in cross section in figure 4. Ostracodes and foraminifers identified in the well cuttings indicate a Recent age for the entire section penetrated by the test wells. Slides containing the microfossils from all samples collected during the present investigation are on file at the office of the Ground Water Branch, U. S. Geological Survey, Raleigh, N. C.

Correlation of the rock material from the test wells indicates that five lithologic units are identifiable over all or part of the areas, as follows:

Depth in Feet (below land surface)		Thickness in Feet
0-20	Medium- to fine-grained quartz sand containing disseminated shell fragments in the lower 10 feet. Quartz grains have etched and frosted surfaces.	20
20-29	Sandy silt and clay containing peat and disseminated shell fragments.	9
29-42	Coarse- to medium-grained quartz sand containing disseminated shell fragments. Locally, shell fragments are concentrated in layers up to a foot in thickness.	13
42-60	Silty clay containing abundant shell fragments and thin layers of quartz sand.	18
61-66+	Silty sand containing peat and disseminated shell fragments.	5+

The depths and thicknesses given above are approximate, as they represent averages based on composite sampling from different



North Carolina

State Board of Water Commissioners

AVERAGE ANNUAL RAINFALL

1921-1955

Figure 3

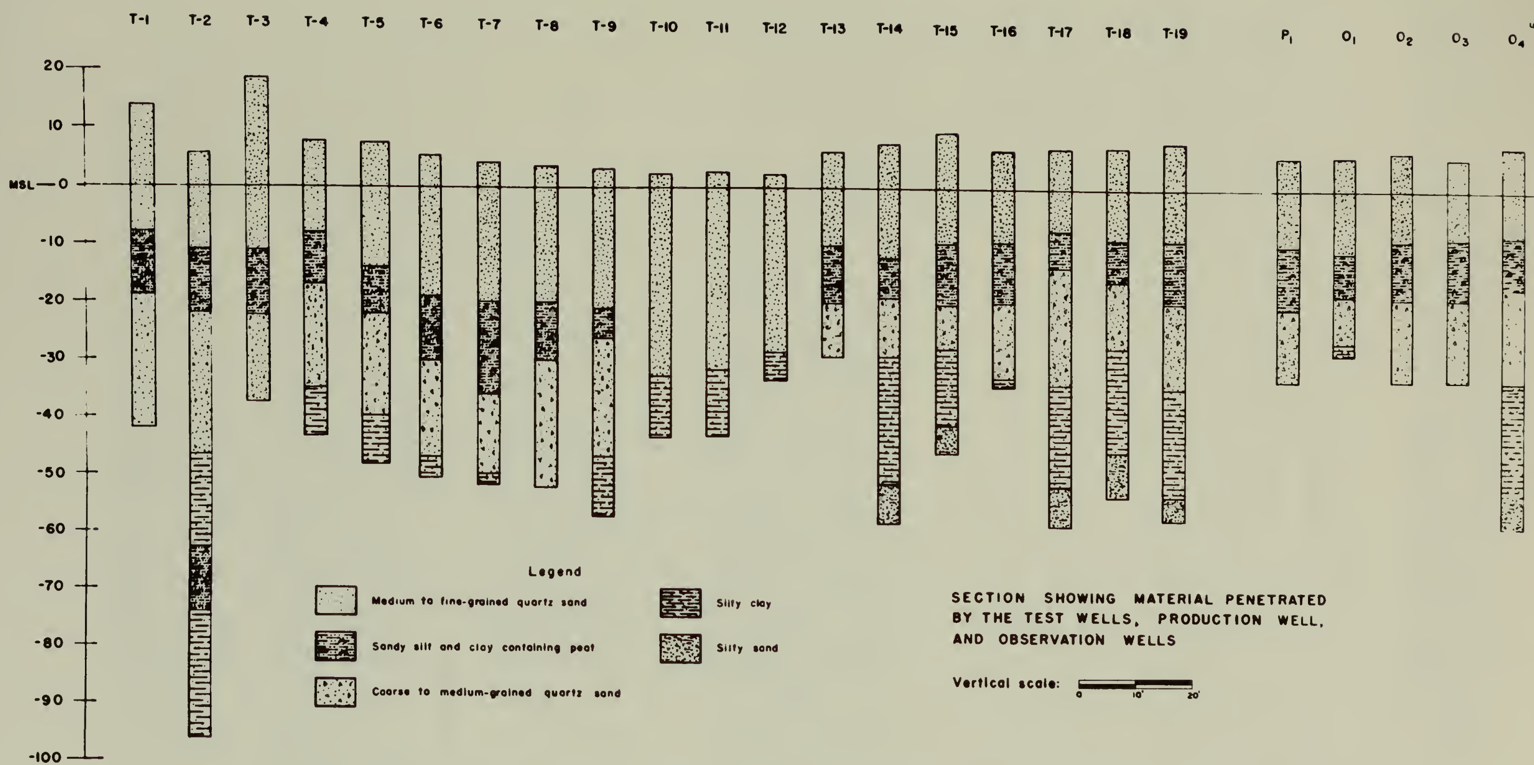

T-1
T-2
T-3
T-4
T-5
T-6
T-7
T-8
T-9
T-10
T-11
T-12
T-13
T-14
T-15
T-16
T-17
T-18
T-19
P1
O1
O2
O3
O4
20
10
MSL — 0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Legend
Medium to fine-grained quartz sand
Sandy silt and clay containing peat
Coarse to medium-grained quartz sand
Silty clay
Silty sand
SECTION SHOWING MATERIAL PENETRATED BY THE TEST WELLS, PRODUCTION WELL, AND OBSERVATION WELLS
Vertical scale:
0
10'
20'

Figure 4

depths in the 19 test wells drilled in the area. All lithologic units are thought to be continuous in the area except the sandy silt and clay between 20 and 29 feet. This unit is absent in 3 of the 19 test wells.

GROUND WATER

Available data on the use and availability of water on Bodie Island indicated that fresh-water supplies were obtained either from cisterns supplied by rainwater or from shallow well points that rarely exceeded a depth of 15 feet. The well points furnish a moderate supply of water that is corrosive and contains objectionable amounts of iron. Several deep wells that had been drilled in the area encountered saline water below a depth of 150 feet. Few data were available concerning the presence of water-bearing material between 15 and 150 feet and the fresh-salt water relationships in this interval. Therefore, the current investigation was concerned primarily with the interval between 15 and 150 feet.

Preliminary measurements of water levels in the area showed that the fresh-water head ranged from less than 1 foot to nearly 5 feet above sea level. The theoretical relation between the head of fresh water above sea level and the position of the fresh-salt water interface below sea level in coastal areas can be computed by use of the so-called Ghyben-Herzberg formula as follows:

$$h = \frac{t}{g-1}$$

where t = head of fresh water above sea level
g = density of sea water (generally about 1.025)
1 = density of fresh water (1.000)
h = depth of fresh water below sea level

Thus, for every foot of fresh water head above sea level there is theoretically 40 feet of fresh water below sea level. Application of this 40-to-1 ratio to the Bodie Island area, where the fresh-water head ranges from less than 1 foot to about 5 feet, indicates that fresh water should extend 40 to 200 feet below sea level. However, water samples from test wells indicate that the maximum thickness of the fresh-water lens on the island is about 60 feet at present. Also, in some areas, the chloride content of the water is higher near the surface than it is at a depth of some tens of feet. The apparent inconsistency of the field data with theory may be the result of several modifying factors, as follows:

1. The sediments are stratified and have a wide range in permeability, which would tend to interfere with establishment of the theoretical equilibrium between fresh and salt water.

2. Sufficient time may not have elapsed to allow the fresh-salt water system to have reached a state of dynamic equilibrium since the last change in sea level.

3. Salt spray, and occasional inundation of the islands by high tides, undoubtedly have resulted in a stratification and mixing of fresh and salt water.

4. Water samples from the test wells reflect, in part, water introduced during the drilling operation and not water indigenous to the aquifers.

AQUIFERS

The available fresh ground water in the area of investigation, at least to the depth penetrated by the test wells, occurs in two shallow aquifers. The upper aquifer (0-20 feet), composed of medium- to fine-grained quartz sand containing disseminated shell fragments, is the present source of ground-water supply on Bodie Island. Water from this squifer is objectionable owing to its corrosiveness and its susceptibility to contamination. The lower aquifer (29-42 feet), separated from the upper aquifer by a discontinuous layer of sandy silt and clay averaging about 9 feet in thickness, is composed of coarse- to medium-grained quartz sand containing disseminated shell fragments and, locally, shell layers up to a foot in thickness. The lower aquifer is suggested as the future source of ground-water supply for the area. Water from this aquifer is adequate for domestic use if treated to remove its hydrogen sulfide content and to lower its moderate hardness.

Underlying the lower aquifer, and separating it from silty sands of low permeability containing saline water, is a layer of silty clay about 18 feet thick. It is expected that the silty clay will serve as a seal to prevent the upward intrusion of saline water into the lower aquifer under pumping conditions.

Upper aquifer.--The water in the upper aquifer occurs under water-table conditions. The water level in a well penetrating this aquifer represents the top of the zone of saturation at any given time. The water level rises in response to rainfall and falls in

response to natural discharge by flow into the adjacent ocean and Pamlico Sound, by evapotranspiration into the atmosphere, and by downward leakage into the lower aquifers. The water level is affected also by the tides.

Lower aquifer.--The water in the lower aquifer occurs under semiartesian conditions. The aquifer is confined below by impermeable clay and partially confined above by a discontinuous layer of silt and clay having a relatively low permeability. The water level in wells penetrating this aquifer represents not the top of the zone of saturation but instead the height of a column of water that will be supported by hydrostatic pressure in the aquifer at a given point of penetration. Where the overlying layer of low permeability is absent, the lower aquifer is in hydrologic continuity with the upper aquifer and the water level in the two is nearly the same.

Quantitative estimates of ground-water supplies.--Aquifers function in two ways: as conduits to transmit water, and as reservoirs to store water. The measure of an aquifer's ability to transmit water is its coefficient of transmissibility, which is defined as the rate of flow of water, in gallons a day at the prevailing water temperature, through each vertical strip of the aquifer 1 foot wide having a height equal to the thickness of the aquifer, under unit hydraulic gradient. The measure of an aquifer's ability to store water is its coefficient of storage, which is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

The data from the test-drilling and water-sampling program (fig. 4 and table 1) indicate that the fresh-water body of greatest lateral extent and thickness lies beneath the high dunes northeast of Theoff Point (fig. 2). Accordingly, this area was selected as a potential supply area and a production well (P_1) and four observation wells (O_1-O_4) were constructed (fig. 2). The purpose of the observation wells was to record the change in the water levels and the chloride content of the water in the area that resulted from steady pumping of production well (P_1).

On May 19 and 20, 1958, a 36-hour pumping test was made to determine the coefficients of storage and transmissibility of the lower aquifer. In conjunction with the pumping test, samples of water were collected every hour from wells P_1 and O_4 for analysis

of chloride content. Field determinations of chloride content were made by the National Park Service. Laboratory analyses shown in table I were made by R. L. McAvoy, Quality of Water Branch, U. S. Geological Survey.

Analysis of the data collected during the pumping test, in which well P_1 was pumped at a steady rate of 50 gpm, indicates that the lower aquifer has a coefficient of transmissibility of 9,800 gallons per day per foot and a coefficient of storage of 0.0019. The coefficients were computed from the test data by Richard Pusey, Ground Water Branch, U. S. Geological Survey. They indicate a

Table I - Chloride content of water from the test wells

Well Number	Depth of sample (feet) / Chloride content (ppm)							
T-1	9-11 / 55	14-16 / 52	19-21 / 352	24-26 / 2,630	44-46 / 2,510	49-51 / 6,600	54-56 / 1,450	
T-2								99-101 / 14,000
T-3			34-36 / 5,250	39-41 / 310	44-46 / 3,250	49-51 / 5.600		
T-4	9-11 / 44	14-16 / 104	19-21 / 2,700					
T-5				24-26 / 5,100				
T-6		14-16 / 52	19-21 / 352	24-26 / 2.630	44-46 / 2.510	49-51 / 6,600		
T-7	9-11 / 31	14-16 / 57	19-21 / 165	24-26 / 522	39-41 / 10.200			
T-8			34-36 / 5.250	39-41 / 310	44-46 / 3.250	49-51 / 5.600	54-56 / 2,450	
T-9			29-31 / 5,250	34-36 / 16.800	44-46 / 17,500	59-61 / 20.800		
T-10			19-21 / 5.500	39-41 / 2,600	44-46 / 6,500			
T-11			19-21 / 860	34-36 / 1.250	44-46 / 8,500			
T-12	9-11 / 254	14-16 / 398	34-36 / 1.920					
T-13				24-26 / 40	29-31 / 38	34-36 / 775		
T-14				34-36 / 20	49-51 / 208	64-66 / 3.370		
T-15	4-16 / 13	34-36 / 20	39-41 / 36	44-46 / 865	54-56 / 6,960			
T-16			34-36 / 4,900					
T-17	4-6 / 16	39-41 / 470	44-46 / 1,150					
T-18	4-6 / 14	24-26 / 29	29-31 / 24	59-61 / 12.600				
T-19			34-36 / 16	64-66 / 6.610				

moderately but not highly productive aquifer under semiartesian conditions.

The chloride content of the water from well P_1 ranged from 73 to 85 ppm during the 36-hour pumping test. The chloride content of the water from well O_4. during the same period, fluctuated between 9,000 and 13,000 ppm. However, no consistent trend in the chloride content of the water from well O_4 could be correlated with the pumping of well P_1.

"Safe yield."--The term "safe yield" as used in this report means the amount of water that can be withdrawn from the lower aquifer, by means of a well or group of wells pumped at a constant rate. without causing salt-water encroachment.

In an area surrounded by salt water any lowering of fresh-water head to sea level or below would result in salt-water encroachment if the fresh-salt water system were in dynamic equilibrium. The cone of depression that resulted from pumping well P_1 at a constant rate of 50 gpm for 36 hours is plotted in figure 5. The theoretical cone of depression that would have resulted if well P_1 had been pumped at a constant rate of 25 gpm for 36 hours also is plotted in figure 5. The drawdown in well P_1 at a pumping rate of both 50 and 25 gpm should have been sufficient to result in salt-water encroachment into the lower aquifer. However, the chloride content of the water from wells P_1 and O_4 showed no significant increase in response to pumping during or at the completion of the pumping test. It is apparent that the layer of silty clay between 42 and 60 feet is relatively impermeable and acts as a seal to prevent the upward movement of salt-water into the lower aquifer in response to a decrease in head. It is the writer's opinion that this clay seal would be effective in preventing the upward movement of salt water into the lower aquifer in response to the lowering of fresh-water head that would be induced by the steady pumping of 25 gpm, but that continued pumping at a rate of 50 gpm would result in salt-water encroachment. Therefore, with the proper safeguards. it is estimated that 25 gpm can be pumped safely from individual supply wells in the area that are far enough apart not to interfere with each other.

Owing to limitations in time and funds, the test-drilling program was not comprehensive enough to determine the size and shape of the fresh-water body on the island. However, consideration of the available geologic and hydrologic data suggests that not less

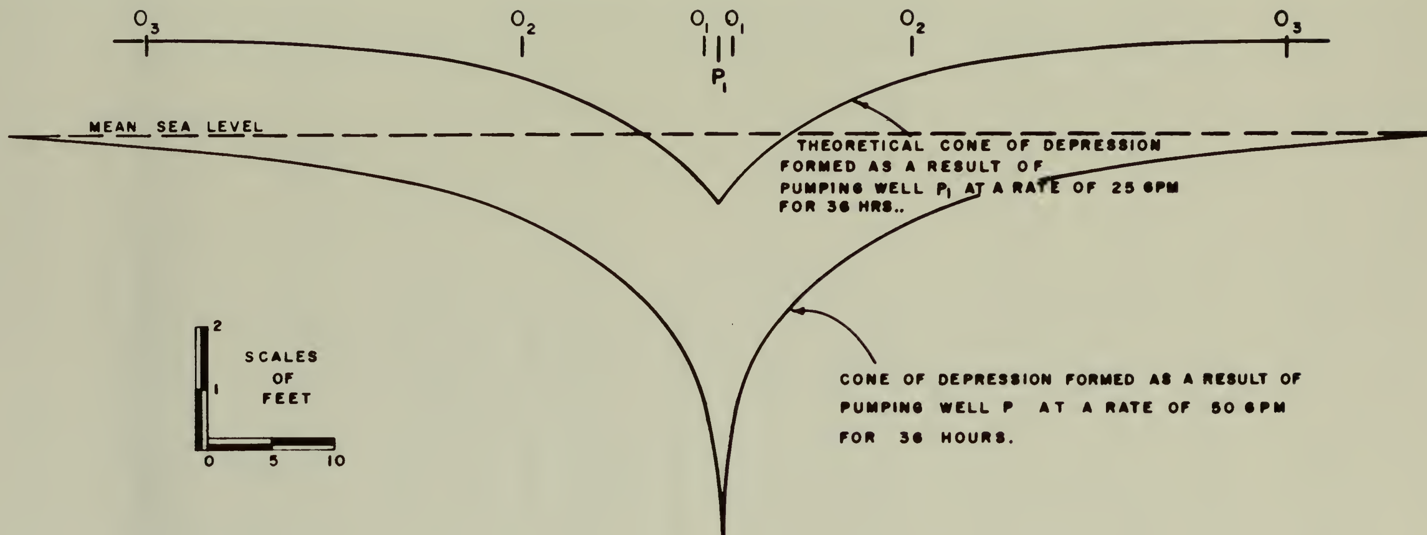

O3
O2
O1 O1
P1
O2
O3
MEAN SEA LEVEL
THEORETICAL CONE OF DEPRESSION
FORMED AS A RESULT OF
PUMPING WELL P1 AT A RATE OF 25 GPM
FOR 36 HRS..
SCALES
OF
FEET
2
1
0
5
10
CONE OF DEPRESSION FORMED AS A RESULT OF
PUMPING WELL P AT A RATE OF 50 GPM
FOR 36 HOURS.

Figure 5

than 150 to 200 gpm can be pumped safely in the area of investigation. To prevent the total draft from being concentrated in a single small area, it is suggested that individual supply wells be separated by a distance of 100 feet, not exceed a depth of 42 feet, and be pumped at a rate not exceeding 25 gpm each.

QUALITY OF WATER

In ground-water development in small areas surrounded by salt water the predominant limiting factor is most often the chloride content of the water. Therefore, in such areas it is necessary to collect numerous water samples for determination of chloride content. These determinations govern the location and depth of additional test wells and show the shape, extent, and chloride content of the fresh-water body.

Just prior to the completion of the 36-hour pumping test a sample of water was collected from well P_1 (fig. 2). The analysis given in (table 2) indicates a water that could be made satisfactory for domestic use by removal of the 3.4 ppm of hydrogen sulfide (H_2S) and softening to lower the moderate hardness of 179 ppm.

SALT-WATER ENCROACHMENT

As in any small area bounded by salt water, the possibility of salt-water encroachment into the fresh-water supply in the Bodie Island area as a result of excessive withdrawal is very real, and procedures to detect any such encroachment at an early stage should be established. In addition, these procedures will enable refinement of the estimate of "safe yield" made earlier in this report, and will facilitate safe development of the water supply.

The test drilling and water sampling done to date indicate that the lateral permeability of the aquifer containing fresh water is much greater than the vertical permeability of the section beneath it. Therefore, it is expected that salt water, if it encroaches, will move horizontally toward the wells rather than upward from below. Nevertheless, both avenues of possible encroachment should be under observation. The following suggestions are designed to give adequate notice so as to prevent salt-water contamination of the supply area:

1. Water levels in one or more observation wells in the supply area should be recorded weekly.

2. The chloride content of the water from each supply well should be determined monthly during the first year of pumping.

3. Frequent determinations, perhaps weekly, of the chloride content of water from a monitor well located between the supply

Table 2 - Analysis of water from well P_1 after 36 hours of pumping at a steady rate of 50 gpm

Date of collection: May 20, 1958 — Temperature (°F): 65

(Parts per million)			
Silica (SiO_2)	26	Bicarbonate (HCO_3)	126
Iron (Fe)	*.05	Carbonate (CO_3)	0
Manganese (Mn)	*.00	Sulfate (SO_4)	2.2
Calcium (Ca)	31	Chloride (Cl)	75
Magnesium (Mg)	25	Fluoride (F)	.7
Sodium (Na)	12	Nitrate (NO_3)	.2
Potassium (K)	9.8	Hydrogen sulfide (H_2S)	3.4

(Parts per million)			
Dissolved solids	264	Color	20
Hardness as $CaCO_3$	179		

pH	7.4	Specific conductance (micromhos at 25 C)	472

* In solution when analyzed.

(Analysis by U. S. Geological Survey)

area and Pamlico Sound and screened at the same depths as the supply wells should be made during the first year of pumping.

4. Weekly determinations of the chloride content of water from a monitor well located in the supply area and screened between the approximate depths of 60 and 65 feet should be made during the first year of pumping.

An analysis of these observations at the end of the first year of pumping will determine the extent to which they should be continued thereafter.

A third potential source of salt-water contamination in the supply area is by surface flooding. Natural dune barriers almost completely encircle the supply area, and it is suggested that consideration be given to constructing additional dunes artificially so as to complete the encirclement.

CONCLUSIONS

1. The test-drilling program indicates that saline water is encountered below a depth of 60 feet in the area of investigation.

2. Two relatively shallow aquifers occur in the area between depths 0 and 20 and 29 and 42 feet

3. The lower aquifer is suggested as the source of ground-water supply if certain restrictions on its development are considered, as follows:

a. Individual supply wells should not be pumped at more than 25 gpm.

b. Individual supply wells should be not less than 100 feet apart and not more than 42 feet deep.

c. Total draft in the area northeast of Theoff Point should not exceed 150 to 200 gpm unless additional data indicate a greater rate to be practicable.

4. Observations of water levels and chloride content should be made for at least the first year of pumping, to detect any salt-water encroachment that may occur and to refine the estimate of maximum safe rate of pumping.